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NAVAL POSTGRADUATE SCHOOL

Monterey, California



THESIS

THE DECISION FOR THE OPTIMAL PRICE IN
COMPETITIVE BIDDING: THE CASE OF A
KOREAN CONSTRUCTION COMPANY

by

Cha Young Yoon

December, 1983

Thesis Advisors:

J. W. Creighton
C. R. Jones

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But unfortunately, the theoretical and practical studies
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The purposes of this thesis are; first, to provide a method of determining an optimal competitive bid by a scientific approach, and second, bidding to provide a total system including effectiveness, competitiveness and efficiency. The model presented here can certainly be a powerful and effective tool for competitiveness.

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The Decision for the Optimal Price in Competitive
Bidding: The Case of a Korean Construction Company

by

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Submitted in partial fulfillment of the
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I. OBJECTIVE

Bidding for the right to property or for the opportunity to render service is a relatively pure type of competition [Ref. 1]. Opposing bidders compete for rights or opportunities under rules established by the owner or his consultant who puts the right or opportunities up for bid. Most business, especially most construction companies, are involved in bidding in one form or another, such as bidding for contracts, for concessions, or for licences to use a patent.

During recent years, there has been a surprisingly large amount of bidding for overseas projects in the middle east area. The projects have been for housing, highways, airports, electrification and various plants. Many Korean construction companies have successfully won such international bidding contests, have been awarded the contract and are now working on the projects.

These contracts have greatly contributed to the successful execution of the Korean 5-year (5th, 1976-1980) economic development plan. They initiated the export drive, and improved the economic status of Korea.

Day by day, the competition becomes keener and keener. Up to this time, the relatively less expensive Korean labor has made it possible for their construction companies to

succeed in competitive bidding. But, now the labor rate of Korea has become high compared with that of other developed or developing countries, so that South Korean construction companies can not depend for their competitiveness on their cheap labor rate, and must concentrate their efforts to improve their system of management and the engineering standards to enhance their competitiveness.

Until now, most countries in the middle east have invested their oil income dollars in social welfare, with principal projects in the areas of housing, highways, airports, seaports, etc.

It is expected that after their investment in the field of social welfare they will invest their oil-dollars in industry, for example, petro-chemical plants, textile plants and various power plants. Notice that these are all in the field of heavy industries. To continue to work on these projects, it is necessary to foster the engineering and management systems so as to be of help in generating maximum profits and continuous employment.

Now, it might be valuable to consider what is the most effective item to be considered in submitting a proposal in order to win the contract. The probable criteria for the selection of the acceptable proposal are; the quality of materials to be installed, the quality of engineering, the quality of the technical design, and the financial terms of the offer to be submitted by the participants. The financial

one is the most important because pricing strategy is fundamental in competitive bidding and price directly affects the profit situation of a company [Ref. 2].

Unfortunately, the theoretical and practical studies of these fields are still unsatisfactorily developed. Also the recognition of the scientific consideration of the pricing problem by the decision makers is not sufficient. [Ref. 3]

To meet the need for scientific management and to provide stimulus in competitive bidding, a scientific model utilizing empirically obtained information is presented in this thesis.

The purposes of this thesis are; first, to provide a method of determining an optimal competitive bid by a scientific approach, and second, bidding to provide a total system including effectiveness, competitiveness and efficiency.

II. GENERAL

If a company wants to join in competitive bidding for some projects, the strategy must be managed in one department of the company. In this case, the managing department must prepare the indirect cost estimate for the project and summarize the estimated direct cost from other departments and its own.

For example, in the case of a housing project, the architectural department would be the managing department. It estimates indirect cost and direct cost of architecture, and then summarizes the relevant civil, electric and facility costs prepared in the civil engineering department, electrical engineering department and facility engineering departments.

Direct cost is composed of the estimated cost of the architectural, civil, electrical and facility portions, and total estimated cost is composed of direct and indirect cost.

Figure 1 indicates the process of cost estimation in the "Z" construction company.

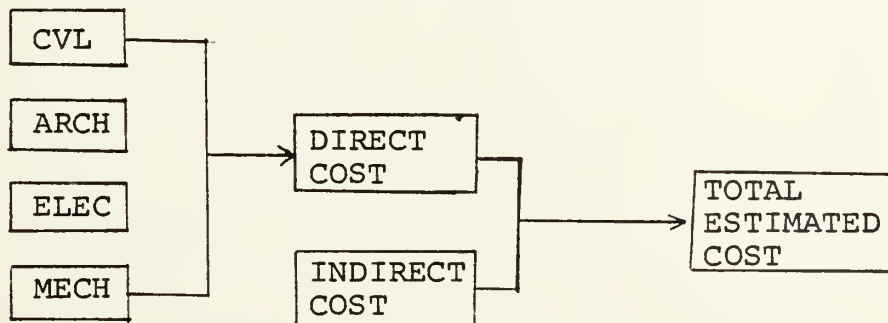


Figure 1. Cost Estimating Process for the Z Construction Company.

The managing department shall be one of these civil, architectural, electrical, or mechanical departments as shown in Figure 1. Finally, to make a price proposal, i.e., bid amount, this estimated cost is multiplied by some factor to provide profit.

The process of determining this multiplying factor has been, until now, entirely by the traditional rule of thumb [Ref. 2]. For example, if the manager wants profit of 25% of total cost in some project, he will choose 1.25 as multiplying factor and only by intuition consider the probability of winning.

This traditional rule of thumb type of bidding procedure should be supported by more precise methods.

III. METHOD

Generally two kinds of competitive bidding situations occur. One is closed (sealed) bidding in which two or more bidders submit independent bids for the right to property or to render service [Ref. 1]. In most cases, only one bid per competitor is allowed and the judge (Central Tender Committee) accepts the highest or lowest bid as directed by the rules.

The other kind of bidding is the auction, or open, bidding in which two or more bidders continue to bid openly on an item of value until nobody is willing to increase the bid, and the last bid is considered the winning bid.

In this thesis, the case of the former, closed (sealed) bidding will be studied.

A method is presented that determines the optimum bid price to generate a maximum expected profit in a competitive bidding situation where each competitor submits only one closed bid, and where the bidding is for one contract. This method makes use of the previous bidding patterns of all possible opposition bidders, and by analyzing these data, the probability of winning the contract for each bid amount can be deduced. Finally, the amount of the bid that generates the maximum expected profit is calculated.

IV. GENERAL MODEL

A. ASSUMPTIONS UNDERLYING THE MODEL

In order to delimit the range of application of the model presented, this section reviews some of the important assumptions underlying the model.

1. The probability distributions of each opposing company are assumed to be continuous, not discrete. [Ref. 4]
Under this assumption, ties have zero probability, and no provision for handling them is needed.
2. A critical assumption about the probability distributions is that each bidder has the same degree of estimating accuracy and will continue the same pattern of estimating behavior. [Ref. 5]
3. The sole objective of each participant is to maximize total expected profit. [Ref. 1]
4. The pattern for cost estimates of the company will not change.
5. All the participants bid under the condition of completely free competition.

B. PROBLEM

Consider a case where the owner or his consultant invites a large number of companies in the same industry to bid for a contract. Each company interested in obtaining it must submit a closed bid and the company submitting the lowest bid amount gets the contract under the said assumptions.

[Ref. 6]

C. DEFINING THE OBJECTIVE

In the process of decision making, the decision maker who wants to solve some problem must know what the objective is. A decision is a conclusion or termination of a process to do something [Ref. 4]. It initiates actions which in turn generate the need for new decisions. The result of decision making might generate a great profit or, perhaps, a great loss for that company.

For example, a company must win a contract in spite of an expected loss to gain experience in that kind of work, so that afterwards it can increase the probability of winning the next project of the same kind. That is, it can be a strong-point to get a prequalification from the owner or his consultant in the long run. Also there might be a case where a company must win a contract in spite of an expected loss in order to keep the employees from losing their jobs. [Ref. 4]

However, if the company already has many projects ongoing it might pursue only those with the greatest profit potential. For a company to adopt any strategy, it is essential that its objective in the bidding be clearly defined. [Ref. 1]

In this case, there can be many possible objectives, and different strategies will result from different objectives.

- a. The most likely objective is to maximize total expected profit.
- b. A second objective might be to gain at least a certain rate of return on investment.
- c. Another possibility is to minimize expected loss.
- d. An objective which can be found in a true competitive situation is to minimize the profits of competitors. A competitor making a great deal of money will generally become a stronger competitor and in the long run hurt one's company.
- e. It might be important to obtain the contract, even at a loss, in order to keep production and employment going.

These, and other objectives, as well as combinations of these objectives, are found in a bidding problem. [Ref. 1]

As was mentioned in the section on underlying assumptions, it is assumed that the opposing company's sole objective is to maximize total expected profit, and one's cost estimating pattern and opposing company's pattern of bidding behavior have not changed.

D. MODEL BUILDING

If the company has worked in that field for years, it can have data about the relation between estimated cost and actual cost. The actual cost determined after completion of the project will, of course, differ from the estimated cost. It is important, therefore, to determine the bias and variability of the cost estimate [Ref. 1]. This can be done by studying past data on estimates and actual cost that can be obtained after completion of the project. If

we get the distribution of the actual cost as a fraction of the estimated cost, the estimated cost can be refined.

Let C_e and C_a represent the estimated and actual cost of fulfilling the contract, the ratio of actual to estimated cost is denoted by S . Then $h(S)dS$ is the probability that the ratio of the actual cost to estimated cost is between S and $S+dS$. The probability distribution is displayed in Figure 2. [Ref. 1]

Where $\int_0^{\infty} h(S) dS = 1.$

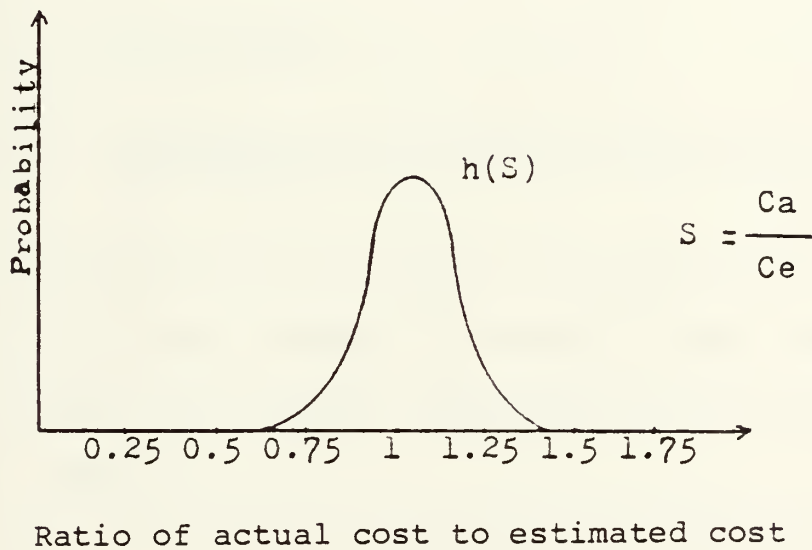


Figure 2. Reliability of cost estimate.

Now if a bid of X wins, the profit will be $X - SC_e$.

Now, let $P(x)$ be the probability that a bid of X will be the lowest and win the contract.

Then the expected profit, $E(x)$ of a bid of X is made,

will be

$$E(x) = P(x) \left[X - \int_0^{\infty} S C e h(S) dS \right] \quad (1)$$

Then value of X for which this expected profit is maximized is the value of X which should be bid.

If $Ce' = Ce \int_0^{\infty} S h(S) dS$ is the estimated cost corrected for bias, then equation (1) becomes

$$E(x) = P(x) (X - Ce') \quad (2)$$

$E(x)$ = expected value of profit

X = bid amount

$P(x)$ = probability of winning the contract at bid amount of X.

If the probability of winning the contract $P(x)$ can be determined for each possible bid amount X, the amount corresponding to the maximum expected value of profit could be found. [Ref. 4]

Now, the probability of winning can be reasoned out as the probability of submitting a bid lower than that of all the other competitors.

If all the participants form their bids independently, the probability of being lower than all the other bids is the product of the probabilities of being lower than each of them separately.

In general, $E(x)$ will look something like the curve in Figure 3.

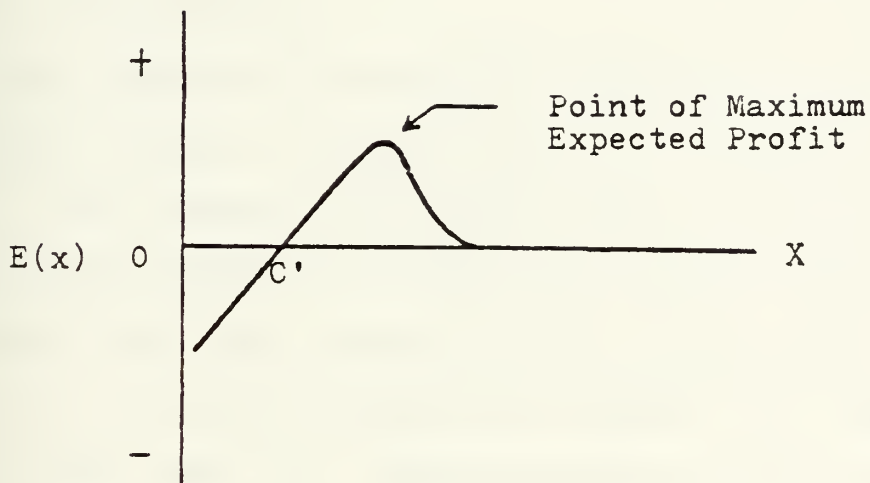


Figure 3. Expected profit vs. Bid Amount

Once the expected profit curve is determined, it is relatively simple to find the bid amount that maximizes the expected profit. [Ref. 1]

The difficulty in determining the expected profit lies in determining $P(x)$, namely, the probability of winning as a function of the bid amount. In the next section, the process of obtaining the probability of winning shall be presented by studying the accumulated past data of the opposition bidders.

E. PROBABILITY OF WINNING AND MAXIMUM EXPECTED PROFIT

One way of determining the probability of winning with a given bid lies in studying previous bidding data accumulated in the company.

Now, suppose we are studying competitor A. On every previous occasion in which A bid and on which our company made a cost estimate, we take the ratio of A's bid amount to our cost estimate. If there are enough previous bids on which A has bid, a pattern of A's bidding behavior relative to our cost estimate will emerge as a distinct distribution [Ref. 4]. These patterns can then be made for all potential competitors. A few examples are shown in Figure 4 [Ref. 1].

If we know which competitors are going to submit their bids, the probability of winning for a given bid can rather easily be computed. Assuming that each competitor is likely to bid as in the past, which is the best assumption in the absence of additional information, the probability of being lower than competitor A by bidding amount of x is the area to the right of the ratio X/C on A's bidding distribution curve in Figure 4 can be seen. [Ref.1]

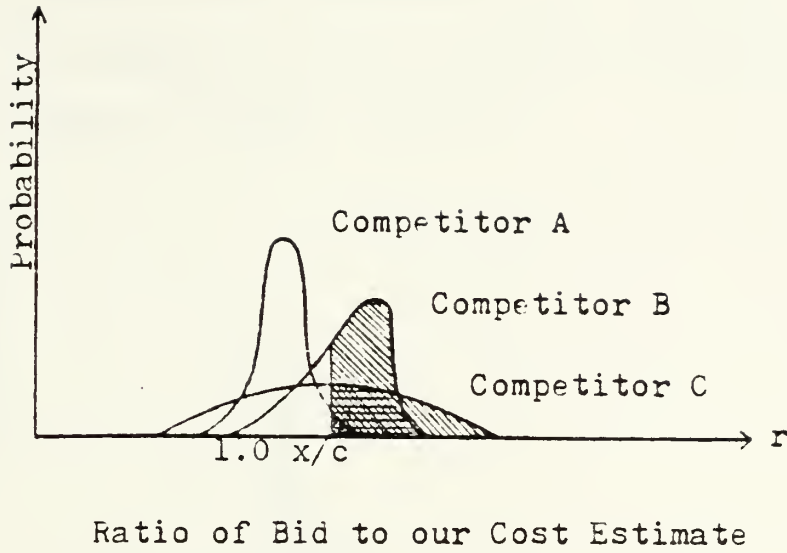


Figure 4. Bidding patterns of competitor A, B, and C.

If $P(x)$ represents the probability of winning, $P(x)$ can be obtained by multiplying the probability of being lower than competitor A, B and C [Ref. 7]. In Figure 4, $P(x)$ is the product of areas to the right of x/c on each bidding pattern, if the competitors are A, B and C only. That is,

$$P(x) = \left[\int_0^{\infty} f_A(r) dr \right] \left[\int_0^{\infty} f_B(r) dr \right] \left[\int_0^{\infty} f_C(r) dr \right] \quad (3)$$

Where, $f(r)$ is the probability density function and

$$\int_0^{\infty} f(r) = 1$$

If it is not known exactly which competitor will participate in the bid, it is necessary to use the concept of an average bidder [Ref. 1]. In this case, the bidding distribution of the average bidder is obtained by combining

all previous ratios on an opposition bid to our cost estimate. The probability density function of average bidder is plotted in Figure 5 [Ref. 1].

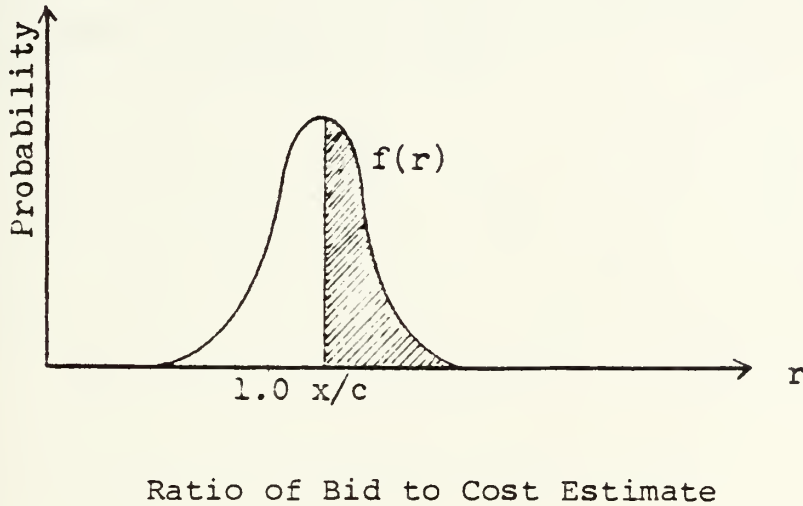


Figure 5. Bidding pattern of average Bidder.

The probability of being lower than K average bidders becomes:

$$P(x) = \left[\int_{x/c}^{\infty} f_a(r) dr \right]$$

Now suppose we don't know all of the probable competitors. For example, if there are five competitors, and three of them are A, B and C, and the others are not known, the probability of winning the contract becomes:

$$P(x) = \left[\int_{x/c}^{\infty} f_A(r) dr \right] \left[\int_{x/c}^{\infty} f_B(r) dr \right] \left[\int_{x/c}^{\infty} f_C(r) dr \right] \left[\int_{x/c}^{\infty} f_a(r) dr \right]$$

So, by applying these probabilities to equation (2), we can obtain the expected value of profit. Finally, if we obtain the expected value of profit for each bid amount and compare these values, we can obtain the maximum expected value of profit at each bid level.

V. CASE STUDY (CASE OF Z CONSTRUCTION COMPANY)

In this section, the case of the Z construction company will be studied by analyzing its past bidding data.

The process of obtaining the optimal price to be submitted in future competitive bidding to generate maximum profit will be presented. The data is from the results of 41 projects in which Z has bid. All of these data are from information provided by Central Tender Committee (CTC) by telex each bid during the the period of January, 1977 to November, 1978. The data is;

- a. Raw data
- b. Ratio of bid to Z's cost estimate
- c. Bidding distribution of each competitor
- d. Cumulative probability distribution
- e. probability of winning, assuming the probable competitors.

A. RAW DATA

Some of the raw data from which the ratio of each opposing company's bid amount to Z's cost estimate can be obtained are shown as a sample in Table I. These raw data are copies of telexes Z has received from CTC in each competitive bidding. The results of all 41 bids are attached at the end of this thesis as an appendix.

Using this raw data, we can understand the rank and bid amount of each participant in each project as indicated by CTC. As shown in Table I, it is customary to announce the result of each bid in the form of a ranking and the bid amount for each participant, this empirically obtained information can be analyzed to determine the optimal bid amount that will maximize expected profit in a future bid.

In Table I, the name of project and the name of participant are eliminated, as they are proprietary.

TABLE I
SAMPLE OF RAW DATA

PROJECT I

No	Tenderer	Bid Amount	Remark
1	A	4,480,000	1.048
2	B	5,093,110	1.191
3	G	5,579,412	1.305
4	Z		(4,275,000)
5	I	6,192,733	1.449
6	OTHER	7,815,300	1.828
7	OTHER	11,205,131	2.621

PROJECT II

No	Tenderer	Bid Amount	Remark
1	D	4,879,000	1.075
2	OTHER	5,073,889	1.117
3	A	5,286,500	1.164
4	B	5,380,140	1.185
5	G	5,566,016	1.226
6	Z		(4,540,500)
7	I	6,440,535	1.418
8	M	8,058,300	1.775

PROJECT III

No	Tenderer	Bid Amount	Remark
1	Z		(7,172,250)
2	D	10,349,551	1.443
3	C	11,024,940	1.537
4	A	11,940,000	1.665
5	I	12,088,709	1.685
6	OTHER	12,183,056	1.699
7	OTHER	14,050,700	1.959

PROJECT IV

No	Tenderer	Bid Amount	Remark
1	B	2,595,782	1.230
2	Z		(2,109,860)
3	A	2,940,000	1.280
4	D	2,951,028	1.399
5	OTHER	3,556,032	1.685
6	M	3,564,007	1.689
7	N	3,582,544	1.698
8	O	3,649,500	1.730
9	C	3,678,000	1.743

PROJECT V

No	Tenderer	Bid Amount	Remark
1	D	4,451,559	1.101
2	Z		(4,042,500)
3	M	5,560,000	1.375
4	S	5,608,000	1.387
5	R	5,940,800	1.470
6	A	6,073,900	1.503
7	K	6,414,254	1.587
8	I	6,433,333	1.591

In Table I, the last column labeled remark contains cost estimates for Z and the ratio of the bid amount to Z's cost estimate for each competitor. The bid amount of Z is not presented as it also is proprietary. In this case study, we assume that the cost estimate is equal to the actual cost obtained after completion of project.

By this assumption, equation (2) becomes:

$$E(x) = P(x)(x-C)$$

B. RATIO OF BID TO Z'S COST ESTIMATE

According to the assumptions, if the bidding pattern of each competitor does not change and neither does Z's pattern of cost estimating, the ratio of bid amount to Z's cost estimate can be a good foundation to predict future behavior of a probable competitor [Ref. 4]. The ratio of the bid amount to Z's cost estimate in each project for every competitor is computed and listed in Table II. The entry in each column indicates the ratio, X_i/C where $i = A.B.....S$.

In Table II, as in Table I, the names of the project and the name of participant are eliminated for proprietary reasons, and instead, are indicated as 1-41 and A-S.

Now, before applying these data to the optimization model, it is necessary to analyze whether these data are reliable and homogeneous. This is done by indicating at the end of column of Table II, columns of meanvalue (M),

value of standard deviation (S) and coefficient of variation (V). In this analysis, formula of

$$M = \frac{\sum_{i=1}^N X_i}{N}$$

$$S = \sqrt{\frac{\sum_{i=1}^N (X_i - M)^2}{N}} \quad \text{and}$$

$$V = \frac{S}{M}$$

are used for mean value, value of standard deviation and coefficient of each variation. The coefficient of variation for each competitor is distributed between 0.0575 and 0.1103 as shown in Table II.

These data can be admitted as reliable and homogeneous.

TABLE II

Ratio of bid to Z's cost estimate and Bidding distribution

Pro- ject Com- petitor	1	2	3	4	5	6	7	8
A	1.048	1.164	1.665	1.280	1.503	1.374	1.618	
B	1.191	1.185		1.230	1.470		1.631	1.362
C			1.537			1.416		
D		1.075	1.443	1.399	1.101			1.261
E						1.362		
F						1.261		1.301
G	1.305	1.226						
H						1.237		
I	1.449	1.418	1.685		1.591		1.646	1.588
J						1.401		
K			1.699		1.587			1.608
L		1.775		1.689	1.375		1.518	1.544
M				1.698				
N				1.730				
O							1.395	
P						1.156		
Q							1.601	1.793
R					1.387			
S							1.618	

Pro- ject Com- petitor	9	10	11	12	13	14	15	16
A			1.131	1.482		1.423		1.541
B		1.067	1.132	1.374	1.472		1.312	1.576
C	1.138		1.301	1.565				
D	1.312					1.519		
E		1.422		1.424	1.557			
F	1.246	1.466	1.443		1.669	1.527		
G								
H	1.344	1.523						
I		1.441			1.375			
J	1.333	1.437	1.333		1.608	1.432	1.379	
K	1.407		1.266			1.533		
L	1.536	1.493		1.467	1.497	1.577		1.628
M				1.514	1.557			
N								
O	1.538		1.134			1.662		1.584
P		1.085			1.342		1.441	
Q						1.477		
R					1.562		1.476	1.600
S				1.522	1.535	1.490		

Pro- ject Com- petitor	17	18	19	20	21	22	23	24
A		1.510		1.691	1.427			
B	1.427	1.347		1.483	1.407	1.524		
C			1.557	1.663				1.633
D		1.597					1.472	
E	1.497			1.647	1.494	1.568		1.307
F		1.474			1.720	1.446		
G						1.427		
H					1.488		1.532	1.629
I	1.577							
J	1.683		1.427		1.629	1.557		1.298
K	1.370	1.592		1.508			1.497	1.650
L			1.742	1.590				
M			1.493					
N						1.491		
O	1.426	1.446						1.321
P	1.493	1.473	1.565	1.578	1.524		1.429	1.529
Q	1.432	1.554	1.673				1.574	1.456
R		1.669				1.547	1.536	
S		1.627		1.724	1.537		1.526	1.574

Pro- ject Com- petitor	25	26	27	28	29	30	31	32
A	1.463		1.413	1.643	1.362	1.527	1.416	1.516
B	1.507	1.493	1.587	1.538	1.423	1.413		1.342
C			1.556		1.527			
D		1.472				1.436	1.362	1.493
E				1.614				
F	1.490	1.556	1.567	1.392	1.417			1.357
G	1.432		1.490					
H			1.390	1.481	1.342		1.510	
I								
J		1.464	1.537			1.362		1.434
K			1.644			1.487		
L	1.607					1.433	1.427	1.372
M				1.367			1.523	1.423
N		1.486	1.527		1.492	1.347		1.397
O								1.463
P		1.434			1.463	1.492		1.523
Q					1.641		1.387	
R	1.718		1.471			1.371	1.492	
S				1.517	1.426	1.453		

Pro- ject Com- petitor	33	34	35	36	37	38	39	40
A	1.457		1.491	1.376	1.493	1.283	1.464	
B	1.220	1.593	1.427	1.347	1.372			1.357
C		1.737		1.364	1.376		1.517	1.436
D	1.287		1.556		1.434			1.319
E	1.486	1.279	1.543					1.542
F		1.468	1.531		1.335			
G	1.465					1.372	1.362	1.446
H			1.621	1.485	1.376		1.464	
I			1.574			1.493		
J		1.536	1.489					
K	1.447				1.456		1.337	
L		1.693					1.470	
M					1.339	1.466		
N		1.412			1.520		1.433	1.452
O		1.494	1.716					
P	1.546	1.576			1.462	1.307		
Q		1.463						1.452
R	1.439			1.444	1.317	1.332		1.411
S	1.367	1.334		1.586	1.402		1.359	

Pro- ject Com- petitor	41	M	S	V
A	1.465	1.437	0.149	0.1037
B		1.394	0.140	0.1004
C		1.488	0.148	0.0995
D		1.385	0.141	0.1018
E		1.482	0.106	0.0715
F	1.357	1.451	0.122	0.0841
G		1.392	0.080	0.0575
H	1.462	1.453	0.102	0.0702
I		1.531	0.096	0.0627
J	1.583	1.470	0.107	0.0728
K		1.405	0.155	0.1103
L	1.300	1.548	0.123	0.0795
M	1.418	1.480	0.104	0.0703
N		1.481	0.095	0.0641
O		1.471	0.153	0.1040
P		1.443	0.131	0.0908
Q		1.534	0.124	0.0808
R		1.486	0.111	0.0747
S		1.506	0.103	0.0684

C. BIDDING DISTRIBUTION OF EACH COMPETITOR

From the data on 41 projects (Table II) we can obtain the frequencies for the occurrence of the various ratio's and hence the corresponding probabilities. In this analysis, an interval of 0.05 was used in the analysis of the ratios. For competitor A and B, the number of occurrences and the corresponding probabilities in each interval (obtained from Table II) is listed in Table III.

TABLE III

Probability Distributions of A and B

DESCRIPTION INTERVAL OF RATIO	COMPETITOR A		COMPETITOR B	
	NUMBER OF TIMES OCCURRED	PROBABILITY	NUMBER OF TIMES OCCURRED	PROBABILITY
1.00-1.05	1	0.036		
1.05-1.10			1	0.033
1.10-1.15	1	0.036	1	0.033
1.15-1.20	1	0.036	2	0.067
1.20-1.25			2	0.067
1.25-1.30	2	0.071		
1.30-1.35			3	0.100
1.35-1.40	3	0.107	5	0.167
1.40-1.45	4	0.143	5	0.167
1.45-1.50	7	0.250	4	0.133
1.50-1.55	5	0.179	3	0.100
1.55-1.60			3	0.100
1.60-1.65	2	0.071	1	0.033
1.65-1.70	2	0.071		

According to the same process, we obtained from Table II the number of occurrences and the corresponding probabilities in each interval for all competitors, A through S. These probabilities for each competitor are summarized in Table IV.

TABLE IV
Bidding Distribution

Number of / Proba-
Occurrence / bility

Compe- titor	1.00 -1.05	1.05 -1.10	1.10 -1.15	1.15 -1.20	1.20 -1.25	1.25 -1.30	1.30 -1.35	1.35 -1.40
A	1 0.036		1 0.036	1 0.036		2 0.071		3 0.107
B		1 0.033	1 0.033	2 0.067	2 0.067		3 0.100	5 0.167
C			1 0.066				1 0.067	2 0.133
D		1 0.059	1 0.059			2 0.118	2 0.118	2 0.118
E						1 0.071	1 0.071	1 0.071
F					1 0.050	1 0.050	2 0.100	3 0.150
G					1 0.111		1 0.111	2 0.222
H					1 0.067		2 0.133	2 0.133
I								1 0.091
J						1 0.153	2 0.105	2 0.105
K						1 0.063	1 0.063	1 0.063
L							1 0.048	2 0.095
M							1 0.111	1 0.111
N							1 0.091	1 0.097
O							1 0.091	1 0.091
P			1 0.090				2 0.105	
Q		1 0.053		1 0.053				2 0.154
R							2 0.125	2 0.125
S							2 0.118	2 0.125
TTL	1 0.033	3 0.010	5 0.016	4 0.013	5 0.016	8 0.026	24 0.077	35 0.113

Compe- titor	1.40 -1.45	1.45 -1.50	1.50 -1.55	1.55 -1.60	1.60 -1.65	1.65 -1.70	1.70 -1.75	1.75 -1.80
A	4 0.140	7 0.250	5 0.179		2 0.071	2 0.071		
B	5 0.167	4 0.133	3 0.100	3 0.100	1 0.033			
C	2 0.133		3 0.200	3 0.200	1 0.067	1 0.067	1 0.067	
D	2 0.188	4 0.233	1 0.059	2 0.118				
E	2 0.143	3 0.215	2 0.143	2 0.143	2 0.143			
F	3 0.150	4 0.200	2 0.100	2 0.100		1 0.050		1 0.050
G	3 0.334	2 0.222						
H		5 0.334	3 0.220		2 0.133			
I	2 0.182	2 0.182		4 0.363	1 0.091	1 0.091		
J	4 0.211	3 0.158	2 0.105	2 0.105	2 0.105	1 0.053		
K	2 0.125	3 0.186	2 0.125	2 0.125	2 0.125	2 0.125		
L	2 0.095	5 0.238	3 0.143	2 0.095	2 0.095	2 0.095	1 0.048	1 0.048
M	1 0.111	2 0.222	2 0.223	1 0.111		1 0.111		
N	2 0.182	4 0.363	2 0.182				1 0.091	
O	2 0.182	2 0.182	1 0.091	1 0.091		1 0.091	1 0.091	
P	3 0.158	5 0.262	4 0.211	3 0.151				
Q	2 0.154	3 0.23		2 0.154	2 0.154	1 0.077		1 0.077
R	3 0.188	3 0.188	3 0.187	1 0.063		1 0.062	1 0.062	
S	2 0.118	2 0.118	5 0.292	2 0.118	2 0.118		1 0.059	
TTL	46 0.148	63 0.202	43 0.138	32 0.103	19 0.061	14 0.045	6 0.019	3 0.010

D. CUMULATIVE PROBABILITY DISTRIBUTION

In the data, there are ratios from 1.00 to 1.80 for each competitor. If we sum the probability of occurrence for each interval starting with the interval of highest ratio, we can obtain the cumulative probability distribution of each competitor. This cumulative probability distribution will show the probability that a particular bid, expressed as a multiple of the decision maker's cost estimate, will be lower than the bid of each competitor [Ref. 4].

As a result, data provide the decision maker sufficient information to determine the bid which will give the maximum expected profit, if the probable competitors are known.

The cumulative probability distribution for all competitor is summarized in Table V.

TABLE V

Cumulative Probability Distribution

Compe- titor	1.00	1.05 -1.10	1.10 -1.15	1.15 -1.20	1.20 -1.25	1.25 -1.30	1.30 -1.35	1.35 -1.40
A	1	0.964	0.964	0.928	0.892	0.892	0.821	0.821
B	1	1	0.967	0.934	0.867	0.8	0.8	0.7
C	1	1	1	0.934	0.934	0.934	0.934	0.867
D	1	1	0.941	0.882	0.882	0.882	0.764	0.646
E	1	1	1	1	1	1	0.929	0.858
F	1	1	1	1	1	0.95	0.9	0.8
G	1	1	1	1	1	0.889	0.889	0.778
H	1	1	1	1	1	0.933	0.933	0.8
I	1	1	1	1	1	1	1	1
J	1	1	1	1	1	1	0.97	0.842
K	1	1	1	1	1	1	0.937	0.874
L	1	1	1	1	1	1	1	0.952
M	1	1	1	1	1	1	1	0.889
N	1	1	1	1	1	1	1	0.909
O	1	1	1	0.91	0.91	0.91	0.91	0.819
P	1	1	0.947	0.947	0.894	0.894	0.894	0.789
Q	1	1	1	1	1	1	1	1
R	1	1	1	1	1	1	1	0.875
S	1	1	1	1	1	1	1	0.941
Average bidder (Total)	1	0.997	0.987	0.971	0.958	0.942	0.916	0.839

Compe- titor	1.40 -1.45	1.45 -1.50	1.50 -1.55	1.55 -1.60	1.60 -1.65	1.65 -1.70	1.70 -1.75	1.75 -1.80
A	0.714	0.571	0.321	0.142	0.142	0.071	0	0
B	0.533	0.366	0.233	0.133	0.033	0	0	0
C	0.734	0.601	0.601	0.401	0.201	0.134	0.067	0
D	0.528	0.41	0.177	0.118	0	0	0	0
E	0.787	0.644	0.429	0.286	0.143	0	0	0
F	0.65	0.5	0.3	0.2	0.1	0.1	0.05	0
G	0.556	0.222	0	0	0	0	0	0
H	0.667	0.667	0.333	0.133	0.133	0	0	0
I	0.909	0.727	0.545	0.545	0.182	0.091	0	0
J	0.737	0.526	0.368	0.263	0.158	0.053	0	0
K	0.811	0.686	0.5	0.375	0.25	0.125	0	0
L	0.857	0.762	0.524	0.381	0.286	0.191	0.096	0.048
M	0.778	0.667	0.445	0.222	0.111	0.111	0	0
N	0.818	0.636	0.273	0.091	0.091	0.091	0.091	0
O	0.728	0.546	0.364	0.273	0.182	0.182	0.091	0
P	0.789	0.631	0.369	0.158	0	0	0	0
Q	0.846	0.692	0.462	0.462	0.308	0.154	0.077	0.077
R	0.75	0.562	0.374	0.187	0.124	0.124	0.062	0
S	0.823	0.705	0.587	0.295	0.177	0.059	0.059	0
Average bidder (Total)	0.726	0.578	0.376	0.238	0.135	0.074	0.029	0.01

Competitor	Total	
A	28	1
B	30	1
C	15	1
D	17	1
E	14	1
F	20	1
G	9	1
H	15	1
I	11	1
J	19	1
K	16	1
L	21	1
M	9	1
N	11	1
O	11	1
P	19	1
Q	12	1
R	16	1
S	17	1
Average Bidder (Total)	311	1

E. PROBABILITY OF WINNING AND BID AMOUNT THAT CAN
GENERATE MAXIMUM EXPECTED PROFIT

If we know the probable competitors, we can obtain the probability of winning for each bid amount, and finally, we can find the bid amount that can generate maximum expected profit [Ref. 8]. In this model, the possibility of tie bids is not considered.

If we assume Z's cost estimate on this project is C , we can find out the optimal bid amount using the previous Table of Cumulative Probability Distribution.

First, suppose only A is Z's competitor, and Z's bid amount is $1.50C$. According to Table V, the probability that Z will win the contract is 0.321. If Z wins, Z will make a profit of $1.50C - C = 0.5C$. So, the expected profit is $0.5C \times 0.321 = 0.1605C$.

If Z's bid amount is $1.30C$, we obtain an expected profit of $0.821 (1.30C - C) = 0.2463C$.

Proceeding similarly, we can obtain expected profits for each bid amount. These are summarized when only A is Z's competitor in Table VI.

TABLE VI

Z's Expected Profit

Bid, as multiple of cost estimate	Expected profit where A is only competitor
1.00 C	$1.000 \times (1.00C - c) = 0$
1.05 C	$0.964 \times (1.05C - C) = 0.0482 C$
1.10 C	$0.964 \times (1.10C - C) = 0.0964 C$
1.15 C	$0.928 \times (1.15C - C) = 0.1392 C$
1.20 C	$0.892 \times (1.20C - C) = 0.1784 C$
1.25 C	$0.892 \times (1.25C - C) = 0.2230 C$
1.30 C	$0.821 \times (1.30C - C) = 0.2463 C$
1.35 C	$0.821 \times (1.35C - C) = 0.28735 C$
1.40 C	$0.714 \times (1.40C - C) = 0.2856 C$
1.45 C	$0.571 \times (1.45C - C) = 0.25695 C$
1.50 C	$0.321 \times (1.50C - C) = 0.1605 C$
1.55 C	$0.142 \times (1.55C - C) = 0.0781 C$
1.60 C	$0.142 \times (1.60C - C) = 0.0852 c$
1.65 C	$0.071 \times (1.65C - C) = 0.04615 C$
1.70 C	$0 \times (1.70C - C) = 0$

* Maximum expected profit comes from a bid of 1.35 C

Clearly, a bid of 1.35C gives the maximum expected profit, 0.28735C. Consequently, empirically obtained information is sufficient to determine the bid that maximizes expected profit in the case where A is the only competitor.

Next, suppose Z is going to bid on some contract and A,B,F,L,P,R and S are Z's competitors. Now the optimal bid price of Z in this case will be determined. In this case if Z wants to win the contract, Z's bid amount must be lower than that of A,B,F,L,P,R and S's respectively.

For example, suppose Z's bid amount is 1.50C. In this case, the probabilities that Z's bid amount is lower than those of A,B,F,L,P,R and S's are 0.321, 0.233, 0.3, 0.524, 0.369, 0.374 and 0.587 respectively. The probability of the joint occurrence of seven independent events is the product of the probabilities that these seven events occur separately [Ref. 4]. As a result, the probability Z's bid is simultaneously lower than bids of A,B,F,L,P,R and of S is; $0.321 \times 0.233 \times 0.3 \times 0.524 \times 0.369 \times 0.374 \times 0.587 = 0.00095$.

Proceeding similarly, using the Table V, we obtain Table VII that shows expected profits for each Z's bid amount.

As shown in Table VII, if the decision maker of Z knows the competitor, he can find out the bid amount which will generate maximum expected profit using this model.

There might be the case when Z can not know all the competitors. For this case, Z can use the bidding distribution

of the average bidder, the last row of Table V, obtained by combining all previous ratios of an opposition bid to Z's cost estimate [Ref. 4].

TABLE VII

Expected profit for each bid amount

Bid. as multiple of cost estimate	Probability that Z's bid is lower than								R's bid	S's bid	probability of Z's win	profit when Z win	expected profit
	A's bid	B's bid	P's bid	P's bid	L's bid	P's bid	P's bid	P's bid					
1.00C	1	1	1	1	1	1	1	1	1	1	1	0	0
1.05C	0.964	1	1	1	1	1	1	1	1	1	0.964	0.05C	0.0482C
1.10C	0.964	0.967	1	1	1	0.947	1	1	1	1	0.8828	0.10C	0.0883C
1.15C	0.928	0.934	1	1	1	0.947	1	1	1	1	0.8208	0.15C	0.1231C
1.20C	0.892	0.867	1	1	1	0.894	1	1	1	1	0.6914	0.20C	0.1383C
1.25C	0.892	0.8	0.95	1	0.894	1	1	1	1	1	0.6061	0.25C	0.1515C
* 1.30C	0.821	0.8	0.9	1	0.894	1	1	1	1	1	0.5285	0.30C	0.1585C
1.35C	0.821	0.7	0.8	0.874	0.789	0.789	0.875	0.875	0.941	0.941	0.2610	0.35C	0.0914C
1.40C	0.714	0.533	0.65	0.857	0.789	0.789	0.75	0.75	0.823	0.823	0.1032	0.40C	0.0413C
1.45C	0.571	0.366	0.5	0.762	0.631	0.631	0.562	0.562	0.705	0.705	0.0199	0.45C	0.0090C
1.50C	0.321	0.233	0.3	0.524	0.369	0.369	0.374	0.374	0.587	0.587	0.0010	0.50C	0.0005C
1.55C	0.142	0.133	0.2	0.381	0.158	0.158	0.187	0.187	0.295	0.295	0.00001	0.55C	0.000007C
1.60C	0.142	0.033	0.1	0.286	0	0	0.124	0.124	0.177	0.177	0	0.60C	0
1.65C	0.071	0	0.1	0.191	0	0	0.124	0.124	0.059	0.059	0	0.65C	0
1.70C	0	0	0.05	0.096	0	0	0.062	0.062	0.059	0.059	0	0.70C	0
1.75C	0	0	0.05	0.048	0	0	0	0	0	0	0	0.75C	0

* When Z's bid amount is 1.30C, Z can expected maximum profit of 0.1585 C

By applying this model, Z can find out the bid amount that can generate maximum expected profit in future bids. Furthermore, if Z wants to win the contract even at a little profit or at a strategic loss, Z can submit, a bid amount knowing the probability of winning for that bid amount, because Z already knows the relationship between expected profit and competitiveness by using this data.

This model and data can be powerful tools in decision making under various strategies for the decision maker of Z construction company.

VI. VALIDITY TEST

One method of determining the bid amount that can generate maximum expected profit has been presented. A stochastic bidding model similar to the one presented here has been applied by Edelman at RCA (Radio Corporation of America). Edelman's model was based on selecting the bid with the highest expected profit, and the model is based on a payoff matrix arraying the alternative bids for RCS against possible competitive bids.

Edelman has analyzed the sensitivity of this model and also examined the validity of this model [Ref. 9]. In seven tests, the model improved upon the performance of the usual bidding procedure as shown in Table VIII [Ref. 9]. The measure of performance was the percentage by which the bid was below the lowest competitive bid.

TABLE VIII

Seven Tests of the R C A (Ref. 9: p.56)

Test	Bid without model	Bid with model	Lowest competitive bid	Bid without model; percent under(over) lowest competitive bid	Bid with model; percent under lowest competitive bid
1	\$44.53	\$46.50	\$46.49	4.2%	1.1%
2	47.36	42.68	42.93	(10.3)	0.6
3	62.73	59.04	60.76	(3.2)	2.8
4	47.72	51.05	53.38	10.6	4.4
5	50.18	42.80	44.16	(13.7)	3.1
6	60.39	54.61	55.10	(9.6)	0.9
7	39.73	39.73	40.47	1.8	1.8

The model providing the winning bids in all case, was an average of two percent below the next competitive bid, and generated at least as much profit in all cases as the existing procedure. In these tests, the model made a positive contribution to improved decision making, since it increased profits by using the same input information available to the standard decision procedure [Ref. 9].

By the validity test of Edelman, Z construction company can apply the model presented in this thesis and use all the previous data to make a decision of optimal price in competitive bidding without any more testing.

VII. SUMMARY

In summary, the model presented in this thesis provides an optimal price in competitive bidding. The presentation is by a case study of the Z construction company. The process is as follows;

- a. Accumulating past data
- b. Obtaining the probability distribution and cumulative probability distribution for each competitor
- c. Obtaining the probability of winning the contract
- d. Finally, obtaining the bid amount, the multiple of cost estimate, that can generate maximum expected profit.

As explained in the section on the validity test, the scientific approach in the field of competitive bidding can contribute to enhancing profit and competitiveness. During recent years, there has been a surprisingly large amount of bidding for overseas projects, especially in the middle east area. This boom has contributed to the economic development of Korea. But the competition has become keener and keener.

In order to be successful in this field, we must concentrate all of our effort on improving the management system. Furthermore, if every construction company preparing for overseas projects and the Association of Overseas Construction apply this model to improve their system of

management, especially in competitive bidding, the model presented is a powerful and effective tool for competitiveness in the industry.

APPENDIX

(RAW DATA)

*Monetary unit : USD

Pro- ject Com- petitor	1	2	3	4	5	6	7	8
A	4,480,000	5,286,500	11,940,000	2,940,000	6,073,900	3,132,720	5,265,422	
B	5,093,110	5,380,140		2,595,782	5,940,800		5,307,727	7,171,504
C			11,024,940			3,228,480		
D		4,879,000	10,349,551	2,951,028	4,451,559			6,639,697
E						3,105,360		
F						2,875,080		6,850,314
G	5,579,412	5,566,016						
H						2,820,360		
I	6,192,733	6,440,535	12,088,709		6,433,333		5,356,540	8,361,490
J						3,194,280		
K			12,183,056		6,414,254			8,466,798
L		8,058,300		3,564,007	5,560,000		4,939,994	8,129,811
M				3,582,544				
N				3,649,500				
O							4,539,718	
P						2,635,680		
Q							5,210,099	9,440,901
R					5,608,000			
S							5,265,422	

Pro- ject Com- petitor	9	10	11 1,000 USD	12 1,000 USD	13	14	15	16
A			140,850	365,034		91,783,500		6,553,873
B		3,089,605	140,975	338,433	6,664,019		5,848,765	6,702,728
C	14,272,420		162,021	385,478				
D	16,454,671					97,975,500		
E		4,117,543		350,748	7,027,675			
F	15,626,920	4,244,950	179,705		7,533,198	98,491,500		
G								
H	16,856,004	4,410,000						
I		4,172,560		6,206,200				
J	16,718,046	4,160,977	166,007	7,257,869		92,364,000	6,147,444	
K	17,646,129		157,663			98,878,500		
L	19,264,005	4,323,131		361,340	6,756,859	101,716,000		6,923,884
M				372,916	7,027,675			
N								
O	19,289,088		141,224			107,199,000		6,736,752
P		3,141,726		6,057,251			6,423,834	
Q								
R					7,050,243	95,266,500		
S				374,887	6,928,376	96,105,000	6,579,860	6,804,800

Pro- ject Com- petitor	17 1,000 USD	18 1,000 USD	19	20 1,000 USD	21 1,000 USD	22	23	24
A		50,623		24,097	38,529			
B	112,679	45,161		21,133	37,989	5,939,866		5,170,960
C			3,039,887	23,698			4,231,411	
D		53,543						
E	118,206			23,470	40,338	6,111,358		4,138,668
F		49,419			46,440	5,635,857		
G						5,561,804		
H					40,176		4,403,887	5,158,294
I	124,523							
J	132,893		2,786,075		43,983	6,068,485		4,110,169
K	108,178	53,375		21,489			4,303,276	5,224,791
L			3,401,081	22,658				
M			2,914,933					
N						5,811,247		
O	112,600	48,480						4,183,000
P	117,890	49,385	3,055,506	22,487	41,148		4,107,803	4,841,640
Q	113,074	52,101	3,266,365				4,524,620	4,610,482
R		55,957				6,029,510	4,415,386	
S		54,548		24,567	41,499		4,386,640	4,984,134

Pro- ject Com- petitor	25	26	27 1,000USD	28	29	30	31 1,000USD	32
A	4,884,474		18,708	6,931,817	3,315,108	5,936,823	169,155	5,539,782
B	5,031,376	4,456,247	21,012	6,488,822	3,463,582	5,493,603		4,903,950
C			20,601		3,716,718			
D		4,393,567				5,583,024	162,705	5,455,736
E				6,809,466				
F	4,974,618	4,644,289	20,747	5,872,848	3,448,978			4,958,763
G	4,780,975		19,728					
H			18,404	6,248,339	3,266,428		180,385	
I								
J		4,369,689	20,350			5,295,320		5,240,137
K			21,767			5,781,307		
L	5,365,243					5,571,361	170,469	
M				5,767,373			181,937	5,199,941
N		4,435,353	20,217		3,631,528	5,237,000		5,104,931
O								5,346,109
P		4,280,146			3,560,942	5,800,747		5,565,362
Q					3,994,194		165,691	
R	5,735,835		19,476			5,330,311	178,235	
S				6,400,223	3,470,884	5,649,119		

Pro- ject Com- petitor	33	34 1,000USD	35	36	37	38	39	40 1,000USD	41 1,000USD
A	6,204,372		7,803,894	3,570,720	3,878,515	8,000,506	4,738,353		134,686
B	5,195,150	38,326	7,468,918	3,495,465	3,564,182			24,087	
C		41,839		3,539,580	3,574,573		4,909,892	25,489	
D	5,480,458		8,144,104		3,725,245			23,412	
E	6,327,864	30,771	8,076,062					27,371	
F		35,319	8,013,254		3,468,063				124,757
G	6,238,439					8,555,490	4,408,222	25,667	
H			8,484,314	3,853,575	3,574,573		4,738,350		134,410
I			8,238,316			9,310,020			
J		36,955	7,793,426						145,535
K	6,161,789				3,782,397		4,327,307		
L		40,732					4,757,773		119,517
M		33,971			3,478,454	9,141,653			130,365
N					3,948,656		4,638,019	25,773	
O		35,944	8,981,544						
P	6,583,363	37,917			3,797,984	8,150,164			
Q		35,198						23,998	
R	6,127,722			3,747,180	3,421,303	8,306,059		25,045	
S	5,821,123	32,095		4,115,670	3,642,116		4,398,512		

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